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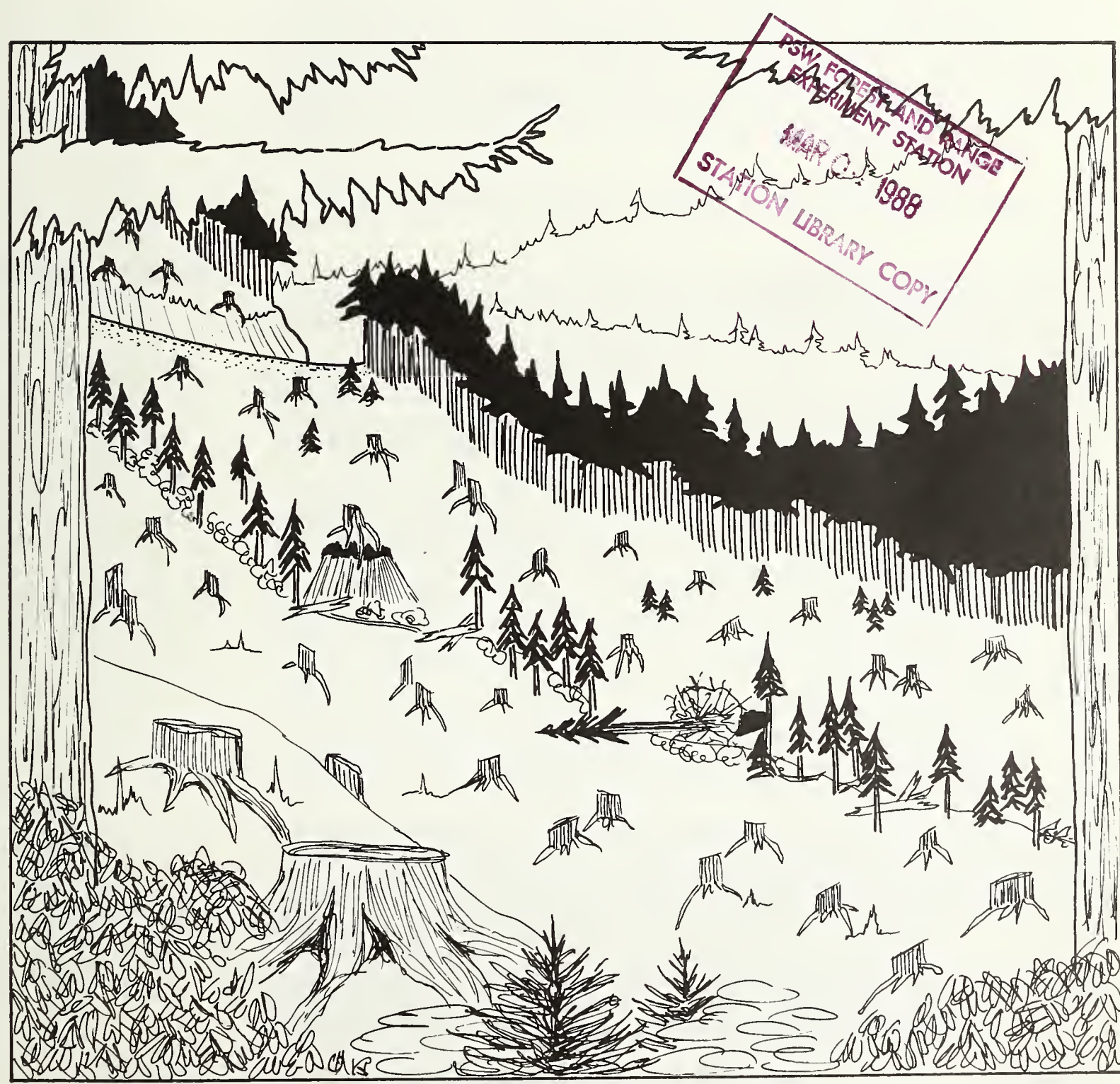
Pacific Northwest
Research Station

Research Paper
PNW-RP-388



Changes in Water Quality and Climate After Forest Harvest in Central Washington State

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Abstract

Fowler, W.B.; Anderson, T.D.; Helvey, J.D. 1988. Changes in water quality and climate after forest harvest in central Washington State. Res. Pap. PNW-RP-388. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 12 p.

Chemical output of nitrate, calcium, magnesium, sodium, potassium, and organic nitrogen were determined on a grams-per-hectare-per-day basis for five treatment watersheds and a control watershed. Water samples were collected from April to October during 3 pretreatment and 3 posttreatment years (1978 to 1983). Except for increased calcium and sodium in several streams, regression equations comparing treatment with control showed no significant difference for pretreatment and posttreatment output. Output generally declined in the posttreatment years. Cyclic changes in output from these and other streams in the eastern Cascade Range in Washington appeared to occur regardless of treatment and were probably related to precipitation. Mean maximum air temperature increased during the posttreatment period in all the small watersheds, but stream temperatures were relatively unaffected.

Keywords: Water quality, sediment production, temperature, logging effects, Washington.

Research Summary

Information about baseline chemical output of streams and changes after timber harvest is limited for the forest zones of central Washington State. This study examined chemical output, climatic change, and turbidity and sediment production after longspan skyline and helicopter logging in four 34- to 169-ha subwatersheds, a main 969-ha watershed, and a 548-ha control watershed. The watersheds were near Wenatchee, Washington. Elevations ranged from 550 to 2130 m, and soil parent materials were ultrabasic metamorphics, overlaid with glacial till in some subwatersheds. Average annual precipitation was about 125 cm.

Water samples were collected from April to October during 3 pretreatment and 3 posttreatment years, 1978 to 1983. Chemical output of nitrate, calcium, magnesium, sodium, potassium, and organic nitrogen were determined on a grams-per-hectare-per-day basis. Mean values for the 6-year period, except for calcium and magnesium, were comparable to values for the Entiat Experimental Forest watersheds and an uncut watershed (Andrews Creek) in the Pasayten Wilderness also located on the east slopes of the Cascade Range. Output of calcium from these small streams was about 5 times higher and magnesium about 20 times higher. Comparing treatment with control, study watersheds showed no significant difference for pretreatment and posttreatment output except for increased calcium and sodium in several streams. Output generally declined in the posttreatment years. Cyclic changes in output from these and other streams appeared to occur regardless of treatment and were probably related to precipitation.

Turbidity and suspended sediment were measured at one location where road construction occurred and at the main gauging station lower on the stream. During high flow, peaks in sediment and turbidity at the main gauging station followed road construction upstream. Sediment accumulated in the stream channel during the low-flow period and was not observed until the next runoff season.

Mean maximum air temperature increased during the posttreatment period in all the small watersheds, but stream temperatures were relatively unaffected. Cooling of stream water below a reconstructed stream crossing was an anomaly.

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Introduction

High-quality water from forested watersheds on the eastern slopes of the Cascade Range in Washington and Oregon supports a multimillion dollar irrigation economy, provides domestic water supplies, and maintains the aquatic habitat for a valuable local and anadromous fishery. Perceived changes in streamflow quality or quantity ascribed to forest management may invite judicial action and present a custodial challenge in achieving multiple use of these lands.

Watershed studies within this forest zone are limited. Watersheds in the Entiat Experimental Forest in central Washington State were to have addressed the question of how logging systems could be designed to minimize hydrologic impacts (Helvey and others 1976a). Wildfire in the early 1970's, however, changed the mission of the Entiat Experimental Forest to documenting wildfire effects and monitoring rehabilitation efforts (Helvey and others 1976b). Tiedemann and others (1978) described the nutrient economy of the Entiat streams for the postfire years of 1971 to 1975 and provided some benchmark nutrient output levels. Unfortunately, only a limited record existed for the prefire period.

The continued need for information on watershed processes under management led to selection of the Hansel Creek and Allen Creek watersheds, the first of a series of new watersheds to be studied. Although 20 watershed complexes were identified for an extensive study of the effects of forest harvest on water quality and yield, only the Hansel and Allen watersheds were developed. This report presents a case history of the changes in streamflow quality and climate of these watersheds as affected by forest harvest.

The Andrews Creek watershed in the Pasayten Wilderness has been monitored since 1975 by the U.S. Geological Survey, U.S. Department of the Interior, for flow and nutrient concentrations. Computed nutrient output from this uncut watershed provided a contemporary record for comparison with this study.

Methods

Watershed Characteristics

The watershed complex (fig. 1) is about 30 km west of Wenatchee in central Washington State. The two major gauged watersheds, Allen Creek (number 7)--the control--and Hansel Creek (number 1), flow easterly from the Mount Stuart Range into the Wenatchee and Columbia River drainages. Table 1 shows total area, percentage treated, and range in elevation of the main and subwatersheds. Portions of four subwatersheds (Hansel 2, 3, 4, and 5) were clearcut; Hansel 6 was not treated.

These watersheds are in the contact zone between the granitic materials of the Stuart Range to the west and the Swauk sandstones to the east. Ultrabasic serpentine and schist are parent materials with rock outcrops of granite and sandstones at upper and lower boundaries, respectively. Glacial till covers schist in watershed numbers 4, 5, and 6. Soils are sandy to loamy, with depths to 1.5 m. McColley (1976) identifies 11 soil types in these watersheds.

Prelogging vegetation consisted of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western larch (*Larix occidentalis* Nutt.), and western white pine (*Pinus monticola* Dougl. ex D. Don) on the south- and west-facing slopes and a gradation to grand fir (*Abies amabilis* Dougl. ex Forbes) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) on the east-facing slopes. Areas not covered by trees, rock outcrops, and fringes of grassy slopes occupied about 15 percent of the area, mainly the upper elevations in watersheds 2 and 3.

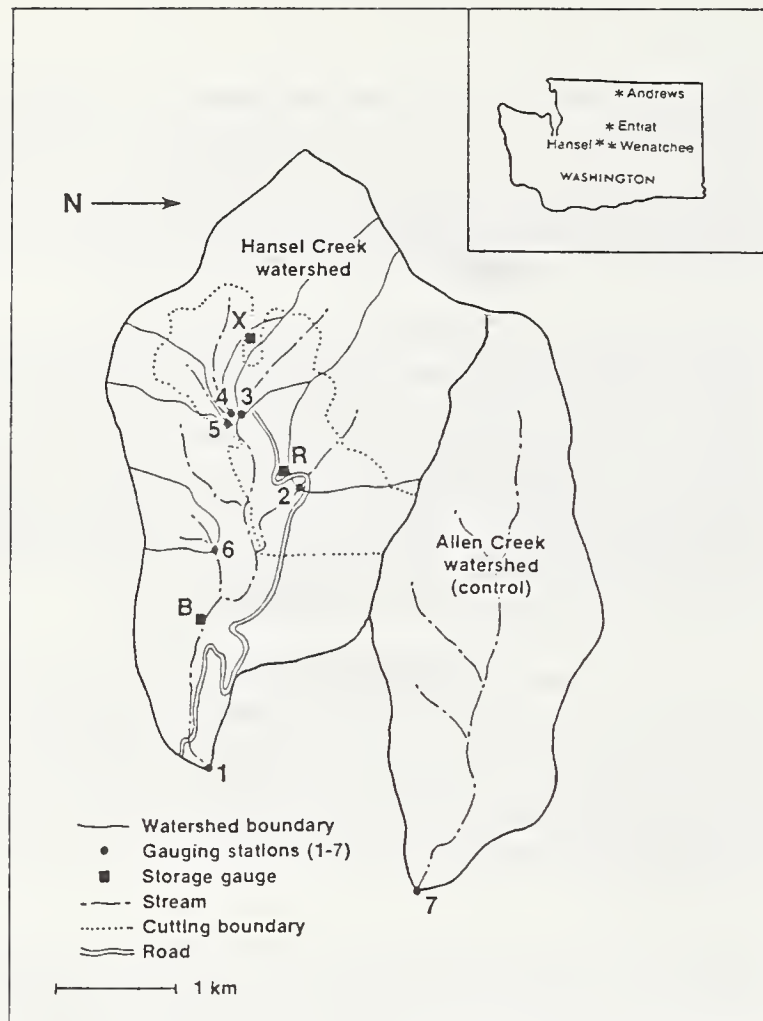


Figure 1--Study area. Inset map shows locations of Hansel watersheds, the Entiat Experimental Forest, and Andrews Creek in Washington State.

Table 1--Characteristics of Hansel Creek and Allen Creek watersheds

Watershed number and name	Elevation		Area	Percentage treated
	Maximum	Minimum		
	Meters		Hectares	
1. Hansel 1	731	2133	869	¹ /26
2. Hansel 2	1075	2098	169	22
3. Hansel 3	1161	2132	82	39
4. Hansel 4	1160	2133	167	22
5. Hansel 5	1158	1673	34	47
6. Hansel 6	969	1417	31	0
7. Allen	548	2011	539	0

¹/ An additional 23 percent had been removed in an earlier harvest.

The lower portion, about 160 ha of the Hansel watershed, is private land. This area was harvested in the 1960's. The main hauling road through this area was reconstructed in 1979, along with the access road into the Wenatchee National Forest, USDA Forest Service, section.

Watershed Treatments

Timing was as follows:

Activity	Period
Weirs and instruments installed	Summer to winter 1977
Roads reconstructed	Summer to fall 1979
Timber harvest	Summer 1980 to summer 1981
Instruments removed	Fall 1983

An earlier pioneering road had crossed the stream in watershed 2. This (about 1 km) section was reconstructed, and an additional 1 km of new road ended at the helicopter-landing area above the gauging station in watershed 3.

Erosion hazard was recognized by the Forest Service as moderate to high. Selection of major logging methods--helicopter and longspan skyline--reflected this concern. The original combination of logging methods was to have been 77 to 92 percent helicopter and as much as 13 percent longspan skyline. Small areas of relatively flat ground below the small watersheds were suitable for shortspan skyline. Some areas were logged by helicopter in the fall of 1980, but a falling timber market made continued helicopter yarding uneconomical. The majority of yarding was done with the longspan system. No distinction is made in this analysis between logging methods--helicopter or longspan skyline. Blowdown of many leave trees in the "longspan" area further reduced its sparse residual overstory. During the hiatus between the two logging methods, about 2500 m³ of downed material overwintered for 2 years on watersheds 3, 4, and 5. This material was removed in 1982. On the Wenatchee National Forest, best management practices required directional felling (away from the stream) in a variable width riparian zone and no ground yarding across the active stream channels. Logging residue was not treated.

Harvested areas are indicated in figure 1. The original sale included the area between watersheds 5 and 6, and watershed 6, in the harvest. Soils in this area, however, were not suitable for road construction, and the change to the longspan skyline precluded harvest.

Volume removed totaled 13 850 m³, distributed as follows:

Species	Volume (m ³)
Douglas-fir	7400
Grand fir	4200
Ponderosa pine	1550
Western larch	450
Western white pine	150
Engelmann spruce	100

Table 2--Water years precipitation based on storage gauges in Hansel Creek

Water year	Storage gauge (elevation)		
	X (1316 m)	R (1133 m)	B (875 m)
	<u>Centimeters</u>		
1979	73.0	68.7	56.6
1980	154.0	140.6	84.3
1981	167.7	135.0	80.3
1982	195.5	175.0	96.2
1983	172.2	169.9	98.8
Mean	152.9	137.8	83.3

Climate and Streamflow

These watersheds have a precipitation regime of winter maximum and summer minimum common to the Pacific Northwest. Expected precipitation in both November and December is 25 to 35 cm. Annual precipitation totals from the three storage gauges in Hansel Creek (X, R, and B in fig. 1) are shown in table 2. Almost twice as much precipitation was recorded at the uppermost (1316 m) gauge (X in fig. 1) than at the bottom (835 m) gauge (B in fig. 1). Precipitation during the 1979 water year was only about one-half the average annual for gauges R (1133 m) and X. Gauge B received about 70 percent of the mean amount in water year 1979. Precipitation was not measured in Allen Creek. Based on nearby stations (at 12-km distance), summer precipitation decreases to an average of about 0.75 cm in the least rainy month, August. Zero precipitation was recorded in some months. Occasional rain-on-snow events resulted in extremely high stream flows. The gauging station in Allen Creek was destroyed in water year 1980 during one of these events. Snow is, however, the predominant form of winter precipitation; maximum depths of 2 m can be expected, with maximum snowpack water content in late April.

Air temperature was monitored at stream gauging stations 2 to 6 in Hansel Creek and at the storage gauges B and R. Temperature was recorded as a 3-hour average. Resolution and accuracy of these recording thermometers was ± 0.2 °C. The maximum temperature recorded was 35.4 °C on the exposed ridgeline at storage gauge R. Minimum temperatures below -10 °C (the limit for this instrument) occurred in all winters. Stream temperature was monitored at all gauging stations, except Allen Creek. Maximum stream temperature did not exceed 13 °C. Minimum temperature for all the streams was 0 °C.

Streamflow was monitored at each gauging station with "H" flumes manufactured to the specifications of Holtan and others¹ (1962). Water stage was measured from April 1 to September 30 with Fisher-Porter¹ digital recorders. High avalanche hazard, roads not suitable for winter access over snow, and freezing of control sections and stilling wells made winter (low flow) recording from these streams infeasible.

¹ The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

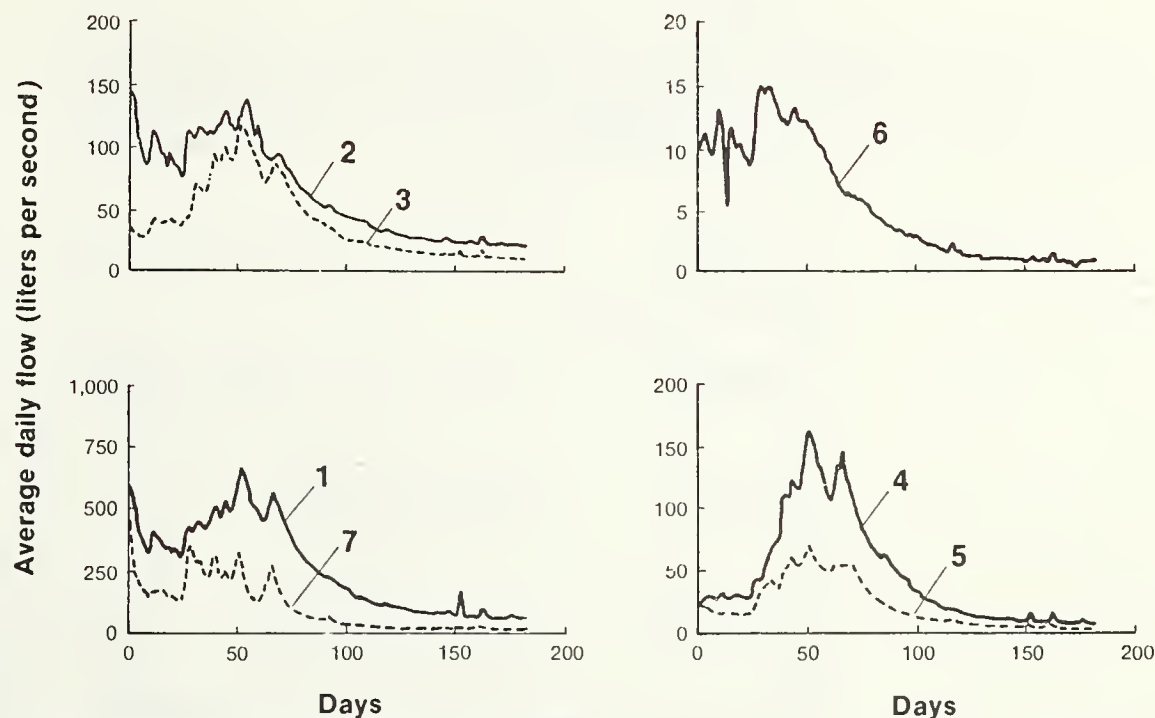


Figure 2--Seasonal runoff patterns for the Hansel Creek streams (1 to 6) and Allen Creek (7), April 1 to September 30, 1978.

Figure 2 presents the average daily flow, based on the 0600- and 1800-hour recordings, from April 1 to September 30, 1978. From the more southerly exposed watershed (2) or where the lower elevation lands were included (for example, the entire watershed complex of Allen Creek (7) or Hansel Creek (1)), flows were already well elevated in April. Watersheds 3, 4, and 5 represented the higher elevation, easterly exposures, and streamflows peaked at the end of May into early June.

Pump samplers operating on an hourly cycle provided an integrated sediment sample at three locations within the Hansel Creek watershed. Samples in watershed 2 were taken 50 m above the road construction, 100 m below the construction, and at the main stream gauging site (1).

Results and Discussion

Water Quality

Water yield (streamflow) data were required for evaluating the changing nutrient status of these watersheds. Thirty-eight flow periods were constructed from the average daily flow records, with midpoints of each period corresponding to the sampling dates for instream physical and chemical components. There were 23 pretreatment and 15 posttreatment periods. The physical properties pH, turbidity, suspended sediment, and conductivity were determined from the water samples. Chemical analysis was for nitrate-N ($\text{NO}_3\text{-N}$), calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^+), potassium (K^+), and organic nitrogen.²

² Samples were analyzed for: nitrate-N (NO_3) by cadmium reduction (Wood and others 1967); dissolved and suspended organic nitrogen by Kjeldahl digestion (Chapman and Pratt 1961) with phenolhypochlorite determination of ammonia; Ca^{++} , Mg^{++} , K^+ , and Na^+ by atomic absorption spectroscopy (Robinson 1966); pH by glass electrode method; and conductivity by conductivity meter (Golterman and Clymo 1969).

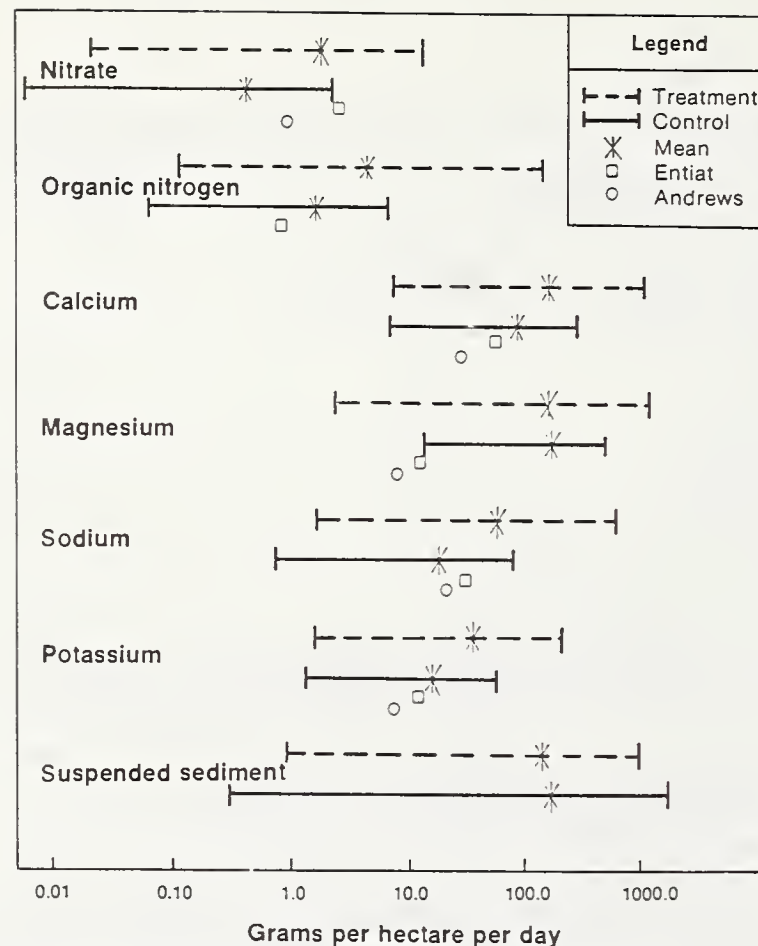


Figure 3--Means and ranges of chemical output from treatment stream (Hansel 2 to 5) and control (Allen Creek) for years 1978 to 1981. Mean values for the Entiat Experimental Forest watersheds and Andrews Creek are also shown.

Figure 3 presents on a logarithmic scale the means and ranges of the combined chemical output from the treatment watersheds (Hansel Creek numbers 2 to 5) and the control watershed (Allen Creek) for all sample periods. For comparison with other east Cascade watersheds, average chemical output from the three Entiat Experimental Forest watersheds from 1971 to 1975 and from the Andrews Creek watershed from 1975 to 1982 is shown. Suspended sediment data were not available from these latter watersheds or for organic nitrogen from Andrews Creek. A variation of more than three orders of magnitude (a thousand times) is shown in the range of the Hansel and Allen Creek data. The mean values are, however, relatively similar between the several watersheds, considering that the watershed areas range from 34 ha in Hansel 5, to 1551 ha for the combined Entiat watersheds, and to 5714 ha for Andrews Creek. Calcium and magnesium output reflect the ultrabasic parent materials in Hansel and Allen Creeks; mean values for magnesium were 20 times higher than in Andrews Creek.

The most rigorous test of the treatment effects in these watersheds is to compare the slopes and levels of the regressions of chemical outputs developed for treatment-control pairs for pretreatment and posttreatment periods. For the 7 variables shown in figure 3 and the 5 treatment-control pairs, 35 combinations were examined. Of these, only calcium in watersheds 3 and 5 and sodium in watershed 3 showed statistically significant ($P < 0.05$) changes (increases) in chemical output compared with the control (table 3). Figure 4 shows the calcium output from watersheds 3 and 7 (control). The calcium output from 3 is essentially equal in the two periods--changing level and slope of the regression equations result from decreased posttreatment output of calcium from the control watershed.

Table 3--Regression equations for properties of streams 3 and 5 found significantly different⁽¹⁾ in pretreatment and posttreatment periods compared with stream 7

Chemical and stream	Pretreatment			Posttreatment		
	Mean	Regression	r^2	Mean	Regression	r^2
Grams per hectare per day						
Calcium:						
Stream 3 (Hansel)	142.79	$Y = 77.14 + 0.716(\#7)$	0.65	140.70	$Y = 42.02 + 1.291(\#7)$	0.93
Stream 7 (Allen)	91.56			73.29		
Stream 5 (Hansel)	308.98	$Y = 79.20 + 2.387(\#7)$.55	332.01	$Y = -2.87 + 5.296(\#7)$.83
Stream 7 (Allen)	96.23			63.23		
Sodium:						
Stream 3 (Hansel)	64.97	$Y = 31.39 + 1.421(\#7)$.61	54.76	$Y = 19.45 + 3.155(\#7)$.89
Stream 7 (Allen)	23.77			11.19		

^{1/} Test for common levels and slopes:
 Calcium:
 Streams 3 and 7. $F = 5.51$, $P = 0.01$
 Streams 5 and 7. $F = 4.21$, $P = 0.02$
 Sodium:
 Streams 3 and 7. $F = 5.06$, $P = 0.01$

The chemical output from watersheds in this geographic area is not constant but varies during the season and among years. This is evident for the calcium output of study streams (fig. 4) and of Andrews Creek (fig. 5). Water year chemical output from Andrews Creek showed a strong relation to yearly precipitation. (Calcium correlated best, $r^2 = 0.93$, followed by sodium, magnesium, and potassium.) As watersheds become smaller, the correlation of chemical outputs to amount of precipitation and the correlation between individual watersheds decrease.

Averages for chemical output for two 3-year periods from Andrews Creek (1975-77, 1978-80) and one 2-year period (1981-82) showed calcium, sodium, and potassium highest from 1978 to 1980; magnesium was highest in 1980 and 1981; and potassium as much as three times higher in 1978-80 compared with the earlier or the later period. Outputs of chemicals and suspended sediments also were highest from the Hansel and Allen watersheds in the 1978-80 pretreatment period and lower in the 1981-83 posttreatment period. Similar variability in yearly output was also reported in the Entiat study (Tiedemann and others 1978). Although nitrate output in all years after the Entiat fire was higher than in the single prefire year, a five-time variability in postfire mean annual rates was shown. For metallic ions the 2d year after the fire, magnesium and sodium output rates were essentially equal to their prefire values; but calcium and potassium were only about 50 percent of their prefire values.

Although most studies of nitrate output after clearcutting show an increase at least the 1st year, some increases are relatively small or are not detected (Vitovsek and Melillo 1979). Martin and others (1984) examined 56 watersheds in New England and found only minor changes in stream chemistry attributable to normal timber harvest. Effects were masked by the buffering action of uncut areas or riparian zones.

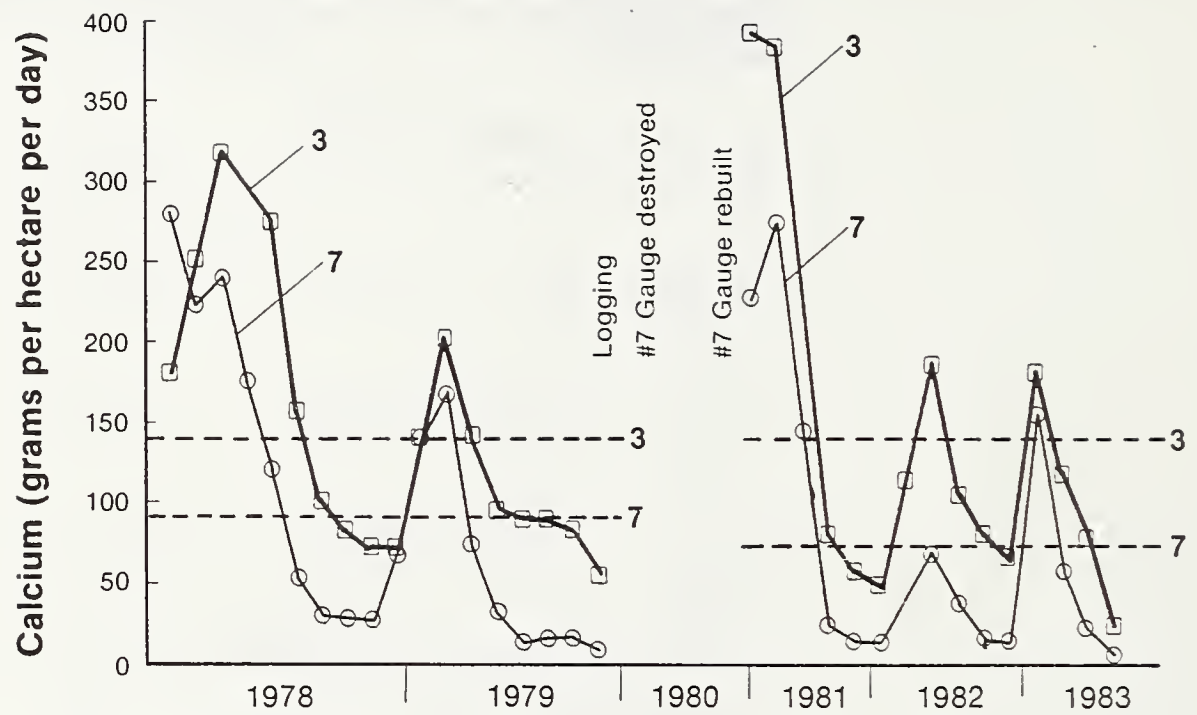


Figure 4--Daily and mean output of calcium for Hansel watershed 3 and control (7, Allen Creek), 1978-83.

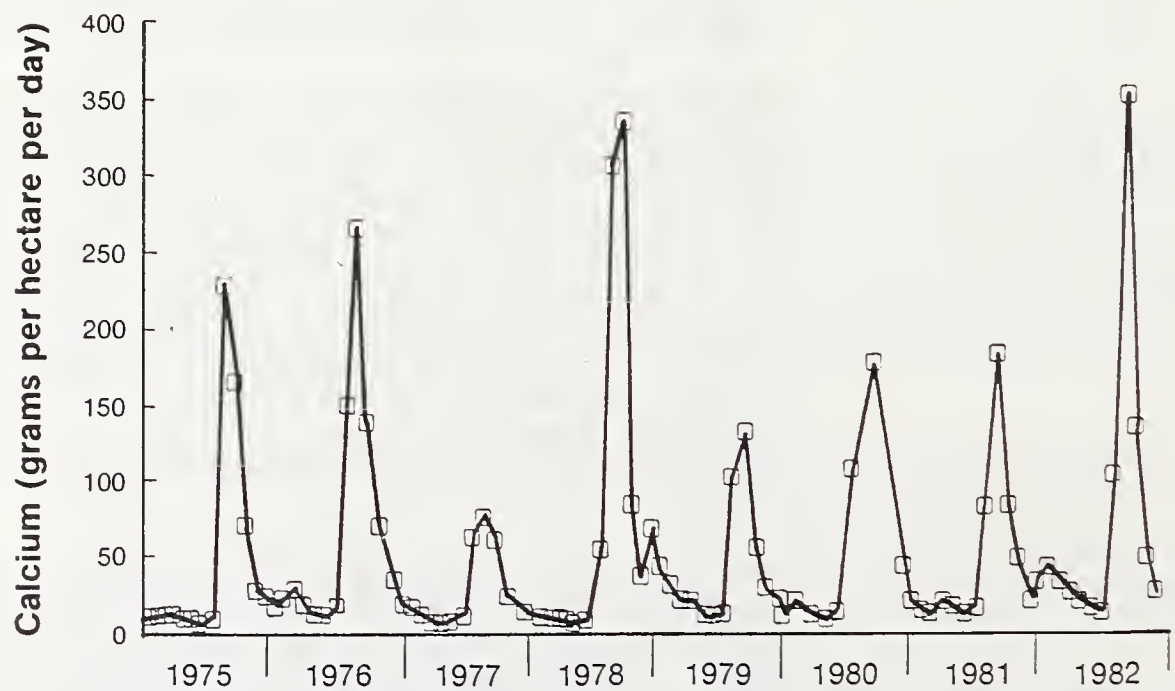


Figure 5--Calcium output for Andrews Creek, 1975 to 1982. Squares are instantaneous values at sampling times.

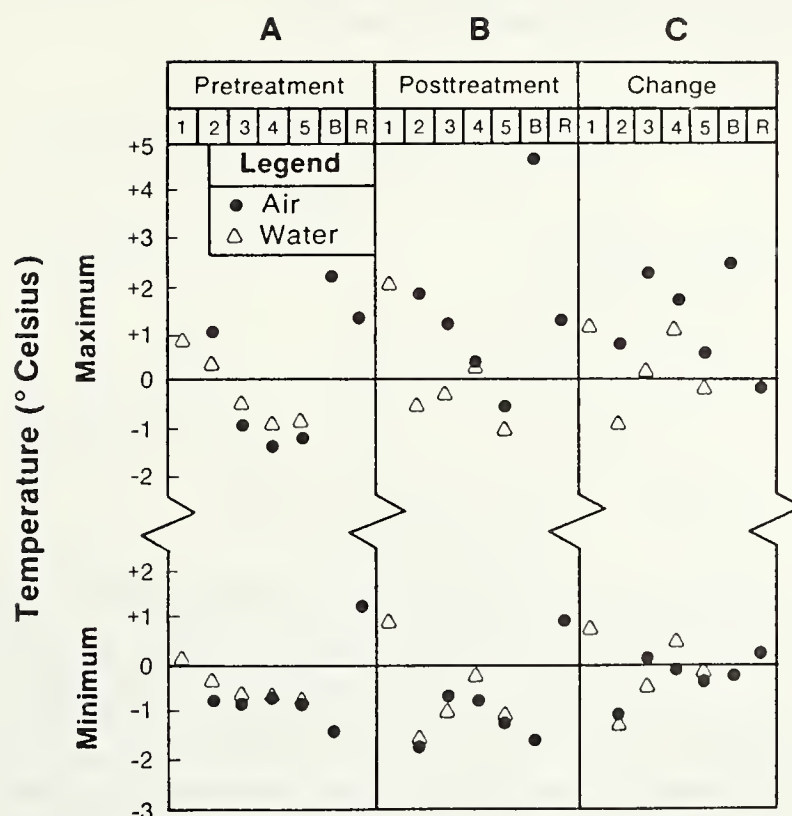


Figure 6--Pretreatment differences and relative change with treatment in mean maximum and mean minimum temperatures between uncut (watershed 6) and treatment watersheds (1, 2, 3, 4, and 5), storage gauge B, and storage gauge R. Air temperature was not measured at number 1 gauge in Hansel Creek watershed.

Air and Water Temperatures

Figure 6, column A, presents pretreatment differences between the mean daily maximum and minimum air and water temperatures compared with temperatures in uncut watershed 6. Column B shows the posttreatment temperature differences and column C the relative changes. In column A, some stream and air temperatures were initially colder (numbers 3, 4, and 5) or warmer (2) and remained so after harvest (column B). Maximum air temperatures at all locations were warmer in the posttreatment period except for the ridgeline (R), which showed no change. Temperatures increased as much as 2.6 °C after insolation increased because of canopy removal. Exposure of the ridgeline location was unchanged. Minimum air temperatures, except for watershed 2 (colder), changed relatively little.

Maximum water temperatures increased by about 1 °C for streams 1 and 4 but showed no change for streams 3 and 5. The maximum for stream 2 was about 1 °C cooler in the posttreatment period. Minimum temperatures showed only small changes, less than ± 1 °C in the long-term average, except for stream 2, which was about 1.5 °C cooler.

The decreases in stream 2 temperature, both maximum and minimum, below the road construction was anomalous. Changes in sunlight absorption by the newly transported, lighter colored streambed materials, position of the sensor in the stream cross section, or decreased exposure by shading from rapidly growing riparian vegetation all probably contributed to the decreases.

Table 4--Average suspended sediment and turbidity in stream 2 above road construction (A), below road construction (B), and at Hansel Creek main station 1 (M), by sampling period

Year	Suspended sediment			Turbidity		
	A	B	M	A	B	M
	Milligrams per liter			NTU ^{1/}		
5/18 to 8/27, 1979:						
Before road construction	3.65	3.72	5.31	0.92	0.96	1.15
After road construction	3.54	178.06	4.75	.95	24.18	1.80
4/23 to 8/20, 1980	5.74	8.53	20.77	1.16	1.31	1.98
5/12 to 10/16, 1981	2.63	2.10	4.30	1.18	1.01	1.43

^{1/}Nephelometric Turbidity Units.

Effects of Road Construction on Sediment and Turbidity

Table 4 shows the mean values of suspended sediment and turbidity near the road construction site in Hansel Creek from 1979 to 1981. Figures 7 and 8 present the 1979 chronology. Nothing about the suspended sediment or turbidity during the preconstruction period was remarkable. The initial peaks of both suspended sediment and turbidity during road construction were followed rapidly by a peak at the main stream site. By early August 1979, streamflow was too low to transport the second peak of material observed below the road construction site downstream to the main stream sampler. This was the lowest runoff year observed for these streams. In 1980, samples taken below the road construction site still showed some elevated values (maximum of 30.0 mg/L and 3.4 Nephelometric Turbidity Units (NTU)), but sediment and turbidity were decreasing to near background values. The main stream site, however, showed elevated suspended sediment values through May, with values as high as 74.0 mg/L; this was at about the peak flow. Apparently, material was deposited in the nearly 2.5 km of stream channel between the road construction site and the main stream site--awaiting the high flows of 1980 to be transported. By 1981, all sites were again near background values.

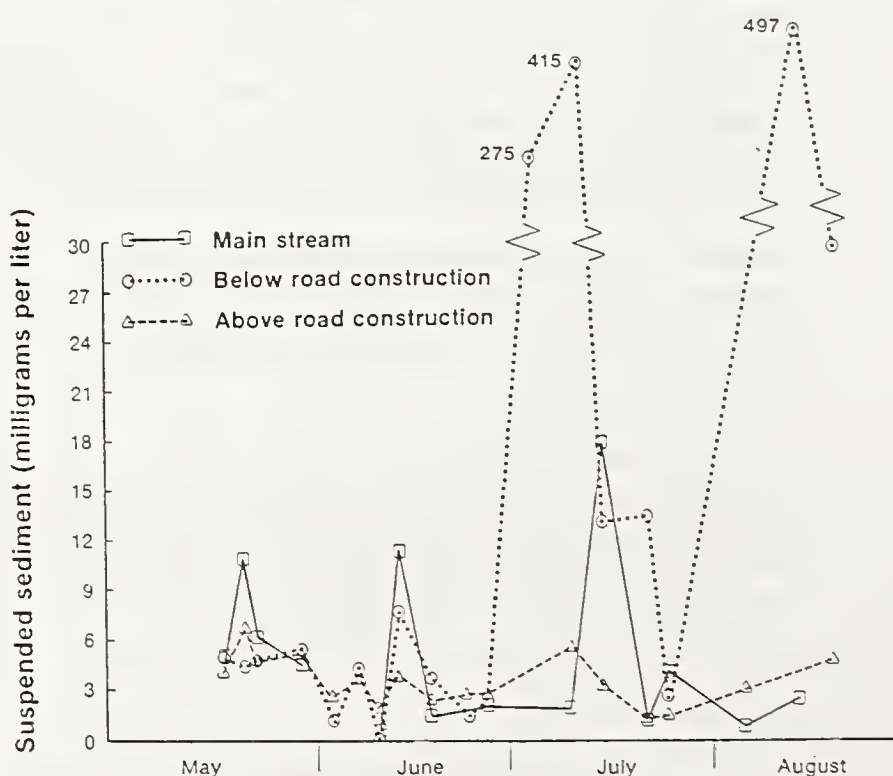


Figure 7--Suspended sediment chronology from three locations in Hansel Creek, 1979.

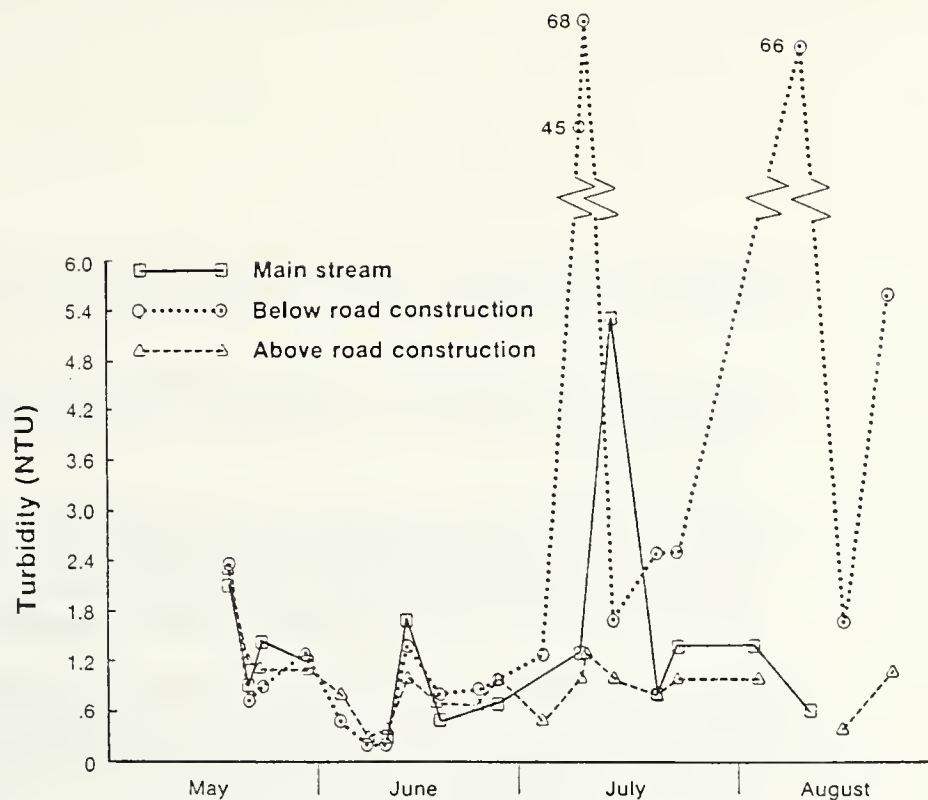


Figure 8--Turbidity chronology from three locations in Hansel Creek, 1979.

Conclusions

In this case study, chemical output from these high elevation, snow-zone watersheds was relatively insensitive to timber harvest. Elevated nitrate outputs have been shown in some clearcutting studies, but in others the response has been small or has not been observed. Clearcutting only portions of watersheds apparently reduced the harvest impact on all nutrient output. The mechanisms of nutrient losses are complicated and influenced by depressed or excessive precipitation. The effects of abnormal climatic events in years before and during this study could not be determined. Nitrate output may have decreased because decomposers immobilized nitrogen in the downed timber that remained onsite for 2 years. Stream turbidity and sediment production increased with road construction but declined rapidly to nearly background levels within 2 years.

Air and water temperatures generally increased with increased site exposure. The anomaly of decreased maximum and minimum temperatures after timber harvest in one stream emphasizes how quickly local conditions may influence thermal conditions in these low-volume streams.

The logging practices used on the Hansel Creek area were effective in protecting the water resource from unacceptable damage. Incomplete streamflow records prevented a rigorous test for changes in water yield after timber harvest. We are convinced, however, from the available records that yield increases were small and hydrologically unimportant. Logging methods and cutting percentages used here should adequately protect the water resource in similar areas of the eastern Cascade Range.

English Equivalents

To convert	To	Multiply by:
milligram (mg)	ounces	0.00003527
milligrams per liter (mg/L)	parts per million	1.0
gram (g)	ounces	0.03527
grams per hectare (g/ha)	pounds per acre	0.0008927
hectare (ha)	acre	2.471
centimeter (cm)	inches	0.3937
meter (m)	feet	3.281
kilometer (km)	miles	0.6214
cubic meter (m ³)	cubic feet	35.31
liter (L)	gallon	0.2642
liters per second (L/s)	cubic feet per second	0.03531
Celsius	Fahrenheit	(9/5 °C) + 32

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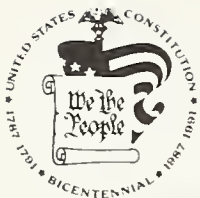
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Keywords: Water quality, sediment production, temperature, logging effects, Washington.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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January 1988

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